

## **SPACE SAVING SURFACE-MOUNTED INDUCTORS**

### **FIELD OF THE INVENTION**

[0001] The present invention relates to structures and methods for augmenting space utilization and heat transfer in electronic devices and, in particular, to structures and methods that provide configurations of a core and winding so as to improve both space utilization and heat flow from a surface mounted inductor formed from these components.

### **BACKGROUND OF THE INVENTION**

[0002] The performance, reliability and lifetime of electronic circuits are affected by the temperature of the various circuit components. Power electronics, in particular, usually have one or more components that generate large amounts of heat, and thus may require heat transfer augmentation structures to dissipate this heat and thereby maintain acceptable operating temperatures. Constraints on the maximum size of a circuit can further increase the difficulty of removing heat, making thermal management an important aspect of power electronics design.

[0003] A particularly difficult problem is the removal of heat from printed circuit board (PCB) mounted inductors and transformers. The operation of the circuit results in the generation of large amounts of heat within the core and a resulting increase in core temperature. Due to the desirability of having the inductor occupy a small surface area of the PCB, and the normal inductor geometry of having a core surrounded by a winding, it can be difficult to transfer heat from the core to the surrounding environment.

[0004] More specifically, prior art transformers, and in particular surface-mounted transformers for power electronics, typically include windings around torroidal cores. The core in such a transformer is surrounded by the winding wires, which wrap around a significant portion, if not the entire outer surface of the torroid. Heat within the core can therefore only be removed by conduction through the wires of the winding to an adjacent heat sink. The torroidal core also wastes space because it includes a large unoccupied hole in its center.

[0005] What is needed is an improved surface-mountable design that provides for improved space utilization as well as enhanced heat transfer from the core of a transformer or inductor to a heat sink. Such an inductor or transformer should have a small footprint, be efficient, inexpensive, and compatible with conventional surface mount technology, such as enabling reflow soldering of the inductor or transformer to a PCB.

### **SUMMARY OF THE INVENTION**

[0006] The present invention solves the above-identified problems of known surface mountable inductions and transformers by providing a winding and core structure that fully occupies available space and provides for coplanar contact of both the core ends and the winding with an adjacent heat sink.

[0007] In a preferred embodiment of the present invention, a surface mountable inductive element comprises a magnetic core having a central elongated portion and two end portions, each said end portion defining an end portion planar surface, and a winding wound about said elongated portion, where the outer surface of said winding defines a planar surface that is coplanar with each said end portion planar surface so as to facilitate surface mounting of said magnetic core and winding on an adjacent structure.

[0008] According to another aspect of the present invention, the inductive element comprises a first magnetic core having a central elongated portion and two end portions, each said end portion defining an end portion planar surface, a first winding wound about said elongated portion, where the outer surface of said first winding defines a planar surface that is coplanar with each said end portion planar surface, and a mounting frame to secure the wire ends of said first winding and to enable said first core and first winding to be surface mounted on an adjacent structure such that a portion of the planar surface of said adjacent structure is in contact with said end portion planar surfaces and said first winding planar surface to enhance heat transfer to said adjacent structure from said inductive element. The inductive element preferably also includes a second magnetic core having an elongated portion and two end portions, each said end portion of said second core defining an end portion planar surface, a second winding wound about said elongated portion of said second core, where the outer surface of said second winding defines a planar surface that is coplanar with each said second core end portion planar surface, and

wherein said mounting frame further secures the wire ends of said second winding and is shaped to affix said first core end portions against corresponding second core end portions and such that the coplanar surfaces of said first core end portions and said first winding are coplanar with the coplanar surfaces of said second core end portions and said second winding.

**[0009]** According to yet another aspect of the present invention, a transformer comprises first and second magnetic cores each having a central elongated portion and two end portions, each said end portion defining an end portion planar surface, a winding about each said elongated portion of said two magnetic cores, where the outer surface of each winding defines a planar surface that is coplanar with each said end portion planar surface of its respective core, and a material for affixing the end portions of said first and second magnetic cores together such that the end portion planar surface of each end portion of said first core is coplanar with the end portion planar surface of each end portion of said second core. The transformer preferably also includes a mounting frame surrounding said first and second cores, wherein said mounting frame secures the wire ends of each said winding and enables said first and second core to be surface mounted on an adjacent structure such that a portion of the planar surface of said adjacent structure is in contact with said end portion planar surfaces and the planar surfaces of each said winding to enhance heat transfer to said adjacent structure from said transformer.

**[0010]** In a preferred embodiment, the adjacent structure on which the inductor or transformer according to the present invention is mounted is a printed circuit board.

**[0011]** It is yet another aspect of the present invention to provide a method of forming an inductive element from a core having a central elongated portion and two end portions for surface mounting to an adjacent structure, e.g., the surface of a printed circuit board or the like. The method includes the steps of forming a winding of wire about the central elongated portion of the core to create a surface on said winding that is coplanar with a surface on each end of said core, and mounting said core in a mounting frame and securing the wire ends of said winding to posts on said mounting frame.

**[0012]** It is another aspect of the present invention to provide an inductive element having a small footprint with improved heat transfer from the transformer core to an adjacent structure,

thereby enabling lower temperature rated materials to be used that in the past for the same applications.

[0013] A further understanding of the invention can be had from the detailed discussion of the specific embodiment below. For purposes of clarity, this discussion refers to devices, methods, and concepts in terms of specific examples. However, the method of the present invention may be used to connect a wide variety of types of devices. It is therefore intended that the invention not be limited by the discussion of specific embodiments.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0014] The foregoing aspects and the attendant advantages of the present invention will become more readily appreciated by reference to the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

[0015] FIG. 1 is a perspective view of an inductive element comprising two cores joined together according to the present invention and mounted on a PCB;

[0016] FIGS. 2A and 2B are side and bottom views of the inductive element of FIG. 1 and FIG 2C is an enlarged view of a mounting frame post with the wire end of a winding secured thereto;

[0017] FIG. 3 is a sectional view along the line 3-3 of the inductive element of FIG. 1;

[0018] FIGS. 4A-4C are views of a first embodiment of an inductive element according to the present invention, where FIG. 4A is a top view, FIG. 4B is a side view, and FIG. 4C is sectional view along the line 4C-4C of FIG. 4A, showing two inductive element cores joined together;

[0019] FIGS. 5A-5C are views of a second embodiment of an inductive element according to the present invention, where FIG. 5A is a top view, FIG. 5B is a side view, and FIG. 5C is sectional view along the line 5C-5C of FIG. 5A, showing two inductive element cores joined together; and

[0020] FIG. 6 is a schematic view of the present invention showing the flow of heat from the inventive inductive element to an adjacent structure.

[0021] . Reference symbols are used in the Figures to indicate certain components, aspects or features shown therein, with reference symbols common to more than one Figure indicating like components, aspects or features shown therein.

### **DETAILED DESCRIPTION OF THE INVENTION**

[0022] To facilitate its description, the invention is described below in terms of a core and winding design for a surface-mounted inductive element, such as a PCB mountable inductor, power choke, or transformer. In general, the present invention is a core and winding configuration that facilitates removal of heat from the core to the exterior of the inductive element by creating a second heat transfer path from the core to the external environment. The device permits the coplanar mounting of the core and the winding to the PCB so that heat in the core can be conducted to the PCB through both the core ends and the winding. It is understood that the inventive device can be used to improve the heat flow from inductors and transformers in general and is particularly useful in removing heat from power converter transformers mounted on printed circuit boards or the like. The scope of the invention is not limited by the following embodiments.

[0023] The present invention will now be described in more detail with reference to the Figures. FIGS. 1-3 are several views of an inductive element **100** structured as a transformer or power choke, according to the present invention, having a surface **101** for surface mounting the inductive element on a printed circuit board (PCB) **10**, where FIG. 1 is a perspective view of the inductive element mounted the surface of the PCB, FIGS. 2A and 2B are bottom and side views of inductive element **100**, respectively, and FIG. 3 is a sectional view 3-3. Power choke/transformer **100** has conventional electrical operating characteristics that are a function of its configuration, as is well known in the field of power electronics. In addition, the mounting and use of surface-mounted transformers is similarly well known in the field and will not be repeated here.

[0024] Inductive element **100** may include a single core having a single winding wound around it. Preferably, it includes a pair of matching cores **110**, individually denoted **110a** and **110b**, and a winding **120** about each core, indicated as winding **120a** and **120b**. More specifically, each core **110** has a pair of ends **111** and an elongated portion **113** that supports the

corresponding winding 120. Each winding 120 is bounded on the inside by elongated portion 113 and defines an outer surface 121, as shown in FIGS. 2 and 3. In addition, each end 111 has a surface 115. Surfaces 115a, 115b, 121a, and 121b are approximately coplanar to define surface 101. Inductive element 100 also has a surface 103 opposite surface 101 that may be coplanar with the surfaces of core ends 111 and windings 120 that are similarly opposite to surfaces 115 and 121, respectively.

[0025] Inductive element 100 also includes a mounting frame 130 having posts 131 adjacent to surface 101. Mounting frame 130 is preferably an insulating material, such as plastic. As shown more clearly in FIGS. 2 and 3, each winding 120 includes a conducting material, such as a metallic ribbon or wire, wound at least once about elongated portion 113. In addition, windings 120 terminate in wires 123 at posts 131. More specifically, each of wires 123 wraps about one of posts 131 and has an exposed portion near surface 101 to facilitate electrical connections between inductive element 100 and conductive traces (not shown) on PCB 10. FIG. 2C is an enlarged view of an exemplary post 131 having a wire 123 wrapped around it.

[0026] Surface 101 of inductive element 100 is mounted on PCB 10 by soldering posts 131 to the PCB, preferably by reflow soldering. As noted previously, surface 115 of core 110 and surface 121 of winding 120 are approximately coplanar and define surface 101. A thin thermally conductive adhesive or paste 140 applied between surfaces 115 and 121 and the surface 142 of PCB 10, provides enhanced thermal coupling between the core 110 and winding 120 and the PCB 10. Heat within core 110 can thus conduct to PCB 10 either through windings 120 or through the ends 111 of core 110.

[0027] In addition, a heat sink 150 may be provided on the side of PCB 10 opposite inductive element 100. The use of heat sinks to remove heat and thus reduce the temperature of heat generating components is well known in the art. Heat sink 150 includes, but is not limited to, the illustrated heat sink, and may include fins, enlarged surfaces that extend beyond the footprint of the inductive element 100, or may include active elements such as thermionic cooling or heat pipes, or any other configuration or devices that effectively promote the transfer of heat from the inductive element to the external environment.

[0028] The scope of the present invention is not limited to transformers or power chokes as shown in FIGS. 1-3. In general, the inventive inductive element is not limited to the size or number of windings on the individual cores, or to the number of cores. It is within the scope of the present invention to provide an inductive element having more than two cores **110** and windings **120**, or an inductor having only a single core and winding. In addition, it is within the scope of the present invention, for multi winding inductive elements, to provide a post for attaching each end of each winding to a PCB via an appropriately sized and shaped mounting frame. Also, it is within the scope of the present invention to mount a heat sink on surface **103** of inductive element **100**.

[0029] A first embodiment of an inductive element according to the present invention is shown at **400** in FIGS. 4A-4C, where FIG. 4A is a top view, FIG. 4B is a side view, and FIG. 4C is sectional view 4C-4C of a core **410** and a winding **420**. FIG. 4C also shows a second core **410b** (in phantom next to a first core **410a**), arranged as an inductive element of the type shown at **100** in FIGS. 1 and 2. Each core **410** includes an elongated portion **413** of length **L** between a pair of ends **411**, and a wire **420** having ends **423** that are wrapped along length **L**. FIGS. 4A and 4B show elongated portion **413** in phantom through the center of winding **420**. Side view FIG. 4B shows coplanar core and winding surfaces, specifically a core surface **415** and a winding surface **421**.

[0030] FIG. 4C shows a sectional view of core **410a** placed side-by-side with core **410b** shown in phantom. Surface **101** of inductive element **400** includes the coplanar surface defined by surfaces **415a**, **415b**, **421a**, and **421b**.

[0031] Elongated portion **413** has dimensions, indicated as a width **W** and a depth **D**, that provide the required electromagnetic properties of windings **420**, as is known in the field. Core ends **411** protrude from elongated portion **413** by a height **D** resulting in ends having rectangular shapes with a depth **E**, width **W+2D**, and height **H+2D**. The dimensions of ends **411** are selected to provide mounting surfaces for winding **420**. Specifically, winding **420** is wrapped along length **L** to occupy a thickness **D**, such that the wire fills in the space between the elongated portion **413** and ends **411**. Alternatively, winding **420** could have another shape that

presents a pair of approximately planar surfaces, not necessarily parallel, for mounting to a PCB and, if desired, an additional heat sink.

[0032] A second embodiment of an inductive element according to the present invention is shown at **500** in FIGS. 5A-5C, where FIG. 5A is a top view, FIG. 5B is a side view, and FIG. 5C is sectional view 5C-5C of a core **510** and a winding **520**. FIG. 5C also shows a second core **510b** (in phantom next to a first core **510a**), arranged as an inductive element of the type shown at **100** in FIGS 1 and 2. Each core **510** includes an elongated portion **515** between a pair of ends **511**, and a wire **520** having ends **523** that are wrapped along the elongated portion. FIGS. 5A and 5B show elongated portion **515** in phantom through the center of winding **520**. Side view FIG. 5B shows the coplanar core and winding surfaces, specifically a core surface **513** and a winding surface **521**.

[0033] FIG. 5C shows a sectional view of core **510a** placed side-by-side with core **510b** shown in phantom. Surface **101** of inductive element **500** includes the coplanar surface defined by surfaces **513a**, **513b**, **521a**, and **521b**.

[0034] Cores **410** include an elongated member **413** that terminates in the center of ends **411**. In contrast, cores **510** include an elongated member **515** that does not terminate in the center of end **511**. As is shown in FIG. 5C, winding **520** thus protrudes beyond the edge in that core's ends **511**, as seen at **525**. It is not necessary for each of the cores to have the same geometry. Thus, for example, an alternative embodiment for a two winding power choke could have one core **410** and one core **510**.

[0035] The inventive inductive element **100**, **400**, **500** differs from the prior art in that it provides two paths for heat conduction from the core to a heat sink.

[0036] FIG. 6 is a schematic view of the present invention showing the flow of heat from the inductive element **100**. Heat core **110** is provided with two conductive paths to heat sink **150** according to the present invention as follows. The novel path, indicated by the arrows labeled **Q1** does not pass through winding **120**. Core **110**, as well as core **400**, **500**, has ends **111** that protrude from elongated portion **113**, which is the central portion of winding **120**. The flow of heat as indicated by arrows **Q1** is thus from elongated portion **113**, through ends **111**, and across



to the surface 142 of PCB 10 (and optionally on to a heat sink 150), where it can be transferred away from inductive element 100. The second path is the conventional path, indicated by the arrows labeled Q2, that passes through winding 120. Heat generated in elongated portion 113 is conducted through winding 120, to PCB 10 (and again optionally to a heat sink 150). The added paths for heat transfer, and in particular path Q1 that bypasses the winding, greatly increases the amount of heat that can be removed from inductive element 100, thereby enabling the ability to better control the temperature of the inductive element.

[0037] In addition to the alternative windings discussed herein, it would be apparent to one skilled in the art that other core configurations, within the scope of the present invention, can be provided to allow the conduction of heat from the core. The inventive inductive element greatly increases the heat flow by providing a significantly enhanced lower thermal resistance pathway from the core to the heat sink, as opposed to prior art inductive elements where the flow of heat is only across the wires of the winding to the heat sink. The improved heat transfer characteristics of the inventive inductive element also allows for a smaller PCB footprint than prior art inductive elements.

[0038] The invention has now been explained with regard to specific embodiments. Variations on these embodiments and other embodiments may be apparent to those of skill in the art. It is therefore intended that the invention not be limited by the discussion of specific embodiments. It is understood that the examples and embodiments described herein are for illustrative purposes only and that various modifications or changes in light thereof will be suggested to persons skilled in the art and are to be included within the spirit and purview of this application and scope of the appended claims.